A Novel Integrated Frozen Soil Thermal Energy Storage and Ground-Source Heat Pump System [1]

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Abstract In this paper, a novel integrated frozen soil thermal energy storage and ground-source heat pump (IFSTS&GSHP) system in which the GHE can act as both cold thermal energy storage device and heat exchanger for GSHP is first presented. The IFSTS&GSHP system can serve as cold energy thermal storage at night, produce chilled water in the daytime in summer and provide hot water for heating in winter. This is followed by its schematic and characteristic description. Then the various operation modes of such system according to different operational strategies are demonstrated in sequence. The system, firstly seen in open literature, is energy-saving, environmental-friendly and promising in the field of air-conditioning systems, and will help solve the problems currently existing with the GSHP system and ITES air conditioning system.

Key words frozen soil thermal energy storage; ground-source heat pump; schematic and characteristic

1 INTRODUCTION

As an environment friendly and energy saving system, ground-source heat pump (GSHP) system is a promising heat and cold source of air conditioning system and has been used in many countries [1]. However, the relative large initial cost and occupied ground area for buried tubes of geothermal heat exchanger (GHE) restricts its wider application to some extent. Moreover, when the system operates for many years in lopsided area where the building load is larger in summer than that in winter, the soil temperature may increase with increasing operating time, thus causing the Coefficient of Performance (COP) of GSHP system gradually decrease because of relative higher condensing temperature [2]. Furthermore, ice thermal energy storage (ITES) device is usually employed to storage cold energy in air conditioning system by producing ice at off-peak electricity time because of its capacity of electricity load leveling, hence the maximum generating capacity and the expenditure of electricity consumption can be reduced [3]. However, this technology is still restricted in air conditioning system for the relative high initial cost for ITES devices and the large area occupied by the ITES devices. Moreover, in currently existing practical application which employs the GSHP and ITES simultaneously, ITES device such as ice storage tanks and coils and buried tubes in GHE for GSHP are separately placed, thus causing the initial cost of such system higher and its control and management more complicated. Therefore, in this paper, a novel integrated frozen soil thermal energy storage and ground-source heat pump (IFSTS&GSHP) system in which the GHE can act as both cold thermal energy storage device and heat exchanger for GSHP is firstly presented. The IFSTS&GSHP system can serve as cold energy thermal storage at night and produce chilled water in the daytime in summer and provides hot water for heating in winter. This is followed by its

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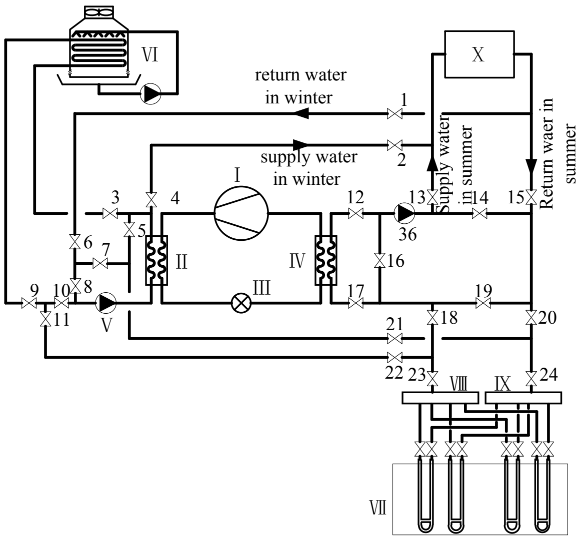
schematic and characteristic description. Then the various operation modes of such system according to its different operation strategies are demonstrated in turns. The system, firstly seen in open literature, is energy-saving, environment friendly and promising in the filed of air-conditioning system, and is helpful to solve the problems currently existed in GSHP system and ITES air conditioning system.



□-Compressor, □-Condenser, □-Expand valve, □-Evaporator, □-circulating pump □-Cooling tower, □-Geothermal heat exchanger, □-Water header , □-Water header □-Users, 1~24-Valve

Fig. 1 Schematics of an IFSTS&GSHP system

2 AN IFSTS&GSHP SYSTEM

As shown in Fig. 1, an IFSTS&GSHP system consists of GHE, three functions chiller having low temperature mode, cooling mode and heating mode, respectively, cooling tower, air conditioning terminal units such fan coil and air handling units, etc., piping, switch valves and control system which are not shown in the figure [4]. The three functions chiller obtained by reforming currently used two functions chiller, can produce -6 °C antifreeze to make frozen soil for cold energy thermal storage at off-peak electricity time at night, and 7 °C chiller water for space cooling in the daytime in summer and provides hot water for heating in winter. Thus, besides having the same function as the traditional GSHP system, the system can fully or partly transfer the cooling load to earth by producing frozen soil at the off-peak electricity time during night for the GHE of such system can be utilized to act as storage device. And then the cold energy stored previously can be released to supplement the cooling load of building at the peak electricity time due to the demand of air conditioning during the daytime. Therefore, it is mainly applicable to areas with lopsided heating loads in winter and cooling loads in summer, and it is more meaningful to develop and utilize the new system in South China. From above, the unique characteristics of the IFSTS&GSHP system can be summarized as follows:

The GHE of such system has dual functions, i.e., extracting or rejecting heat to the soil where the tubes of GHE are buried, and serving as the heat exchanger of frozen soil thermal energy storage, respectively. Therefore, the ice storage balls or ice collection tanks of conventional ice-storage system can be substituted, and hence such problems as large area occupied by the ice storage devices and its high initial cost solved effectively.

The structure and arrangement of the GHE can be changed by adjusting pipe connecting patterns, in order to realize frozen soil thermal energy storage, cooling and heating mode effectively. This is because small space between pipes is beneficial to high quality cool charged in summer as the result of less cool energy loss, and large space helps GHE to escape from insufficiency of heat supply after a long operation period resulting from quick soil temperature field recovery.

The soil temperature around tubes can be adjusted by altering the soil thermal storage strategies or operating cooling tower to release superfluous condensing heat. Therefore, the cooling performance of this system can be improved in summer for the soil temperature doesn't get higher after it runs for a few years.

3 VARIOUS OPERATION MODES OF THE IFSTS&GSHP SYSTEM

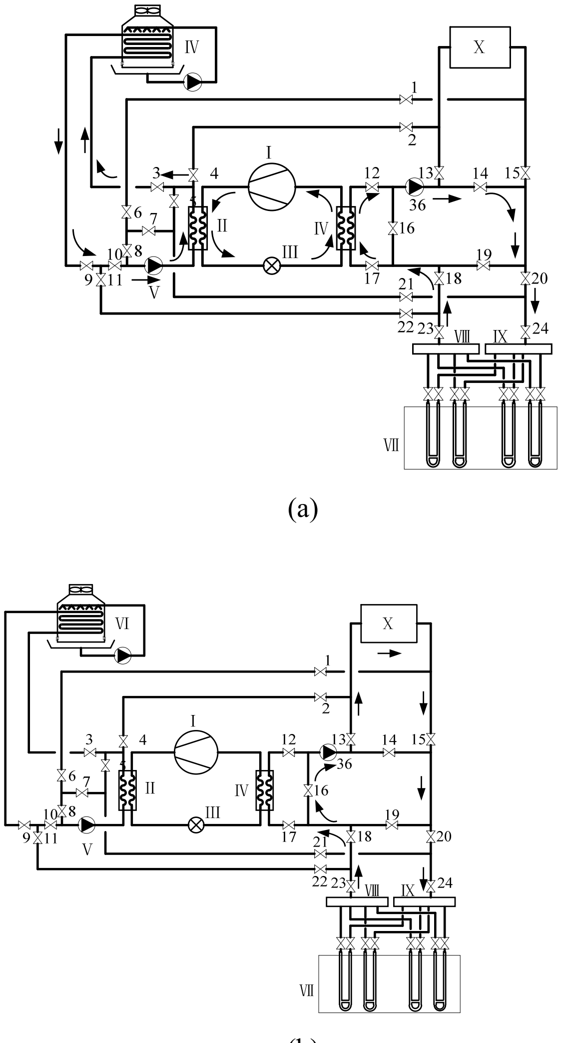
The ISCTS&GSHP system has several operating conditions including storing cold energy into soil in off-peak electricity period at night, and providing air-conditioning by releasing the cold energy stored in soil in peak electricity period in the daytime, in which thaw and frost phase transition courses occur periodically in the surrounding soil around GHE in summer air-conditioning period, supplying heat to buildings in winter heating period and etc.. Such different operative modes of the system can be realized by the switch of valves.

3.1 The Flow of Frozen Soil Thermal Energy Storage and Release

Since the IFSTS&GSHP system combines the advantages the ITES technology and GSHP heat pump technology, it should make use of the off-peak electricity to store cold thermal energy into the soil, thus reducing the operating cost in summer. In this modes, three functions chiller produces low temperature (23 ºF/-5 ºC) chilled fluid which circulates in a piping system including the buried tubes of GHE through a pump to complete frozen soil thermal energy storage. The flow of such operation mode is shown in Fig.2 (a), i.e., heat exhaust loop of cooling tower is □→3→□→9→10→□→□, in which valves 4, 5, 8, 11 are off and valves 3, 9, 10 are open., and cold thermal energy storage loop of GHE: □→12→□→14→20→□→□→□→18→17→□, in which valves 13, 15, 16, 19, 21, 22 are off and valves 12, 14, 20, 18, 17 are open. Furthermore, when the energy stored in the soil is released for space cooling, the antifreeze solution such as 25% glycol solution circulates in the piping system and the buried tubes of GHE by using circulating pump on the load side, which is shown in Fig. 2 (b). In this operation mode, valves 1, 2, 14, 19, 17, 12, 21, 22 are off and valves 13, 15, 20, 18, 16 are open and the flow: □→13→□→15→20→□→□→□→18→16→□.

3.2 Flow of Frozen Soil Thermal Energy Release in Which Chiller Is Serial with GHE

In IFSTS&GSHP system, the space between vertical tubes of heat exchangers cannot be set too small to promise that the chiller can run regularly and high-efficiently both in summer and in winter. At the same time, the chilled water temperature released from the frozen soil is not as low as that of ice storage system because of small heat flux per length buried tubes of GHE resulted from the influence of soil conduction and thermal storage performance. Moreover, compared with the tubes in conventional ice-storage device, there is large temperature difference in the frozen soil between buried tubes of GHE and the nearer to the core tubes, the lower temperature of the soil. This is because that cold energy loss is much more from the outside tube than that from core tube. However, under the drive of temperature difference the soil temperature always tends to be accordance and hence the quality of the cold energy stored in the soil will be degraded and the chilled water temperature released will be higher relatively at the frozen soil thermal energy release mode even if the total quantity stored is equal. And this is the distinct difference between the frozen soil thermal energy storage system and the traditional ice storage system.



(a)

(b)

Fig.2 Flow of frozen soil thermal energy storage and release

In conventional ice storage system, there are two kinds of series loops which are ice priority (chiller upstream) and chiller priority (ice storage upstream), respectively. However, in IFSTS&GSHP system, ice priority should be adopted to promise the chilled water temperature and adequate released cold thermal energy because of energy dissipation of frozen soil. The flow of frozen soil thermal energy release loop that chiller is serial with GHE is shown in Fig. 3 and described as below:

The loop of rejecting condensing heat on cooling tower side:

□→3→□→9→10→□→□, valves 4, 5, 6, 7, 8, 11 are closed and valves 3, 9, 10 are open.

The loop of load side:

□→12→□→13→□→15→20→□→□→□→18→17→□, at this mode the valves 1, 2, 14, 16, 19, 21, 22 are off and valves 12, 13, 15, 20, 18, 17 are open.

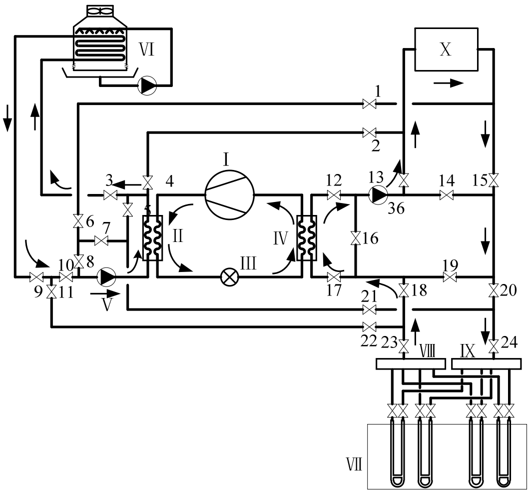


Fig. 3 Flow of frozen soil thermal energy release priority in series

3.3 The Hybrid Flow Using Cooling Tower to Reject Condensing Heat Partly

In the area where the building load is larger in summer than that in winter, the hybrid flow using cooling tower to reject condensing heat partly is adopted to reduce the size and capacity of the GHE, thus lowering the area occupied by the buried tubes and initial cost. In such hybrid flow, the warm water from condenser circulates through cooling tower first to reject part of condensing heat to the ambient and then goes through the buried tubes of GHE. The flow is shown in Fig. 5 and described as follows:

The loop on the cooling tower side: □→3→□→9→11→22→□→□→□→21→7→8→□→□, valves 4, 5, 6, 10, 18, 20 are off and valves 3, 9, 11, 22, 21, 7, 8 are open.

The loop on the load side:

□→12→□→13→□→15→19→17→□, valves 1, 2, 14, 16, 20, 18 are off and valves 12, 13, 15, 19, 17 are open.

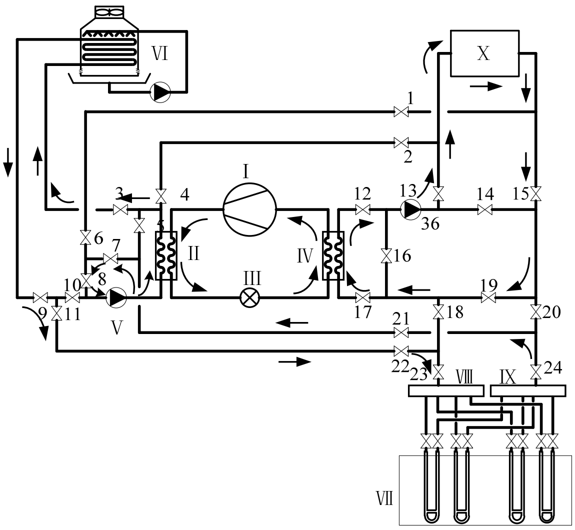


Fig. 4 The Hybrid flow using cooling tower to reject condensing heat partly

3.4 The Flow of Cooling/Heating Mode Like Conventional GSHP System

To ensure the effective recovery of the soil temperature field and the soil energy balance around the buried tubes of GHE, in winter and transition seasons, the IFSTS&GSHP system runs in the same mode as conventional GSHP with the soil as the thermal source/sink. In these two modes, the cooling tower doesn't work, and the GHE, the chillers and the load side operates like conventional GSHP system, which are not show in the article for they are familiar to us all.

4 CONCLUSIONS

In the paper, a novel IFSTS&GSHP system having the advantages of ITES technology and GSHP technology and excluding their respective disadvantages is presented. It is an energy-saving, environment friendly and promising in the filed air-conditioning system, and can be applied in the areas with lopsided heating loads in winter and cooling loads in summer. The schematic and characteristic of such system and the flows of such system according to its different operation strategies demonstrated will help to design and utilize this system. Furthermore, the buried tubes of GHE are a most important part in such system and its heat transfer performance in multi operation modes should be calculated carefully in utilizing the system. .

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